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# Hydrogen at NASA



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## NASA's H<sub>2</sub> Interests



### Space Missions and Aeronautic Development

Enable human exploration of the Moon and Mars



### Institutional Asset Stewardship

Enhance energy efficiency at all facilities to reduce operating costs and natural resource consumption  
(e.g. renewable energy sources, alternatively fueled vehicles)



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## Past and Present H<sub>2</sub> Applications



Centaur, Saturn I/IV/V  
and Space Shuttle  
transportation  
(1960 to today)



Gemini, Apollo and  
Space Shuttle alkaline  
fuel cells (1965 to today)



International Space  
Station life support  
(1999 to today)



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## Present H<sub>2</sub> Space Applications



Hydrogen used as energy carrier and fuel for spaceport and vehicle applications  
For space flight applications, liquefied hydrogen (LH<sub>2</sub>) has been the traditional  
method of choice.

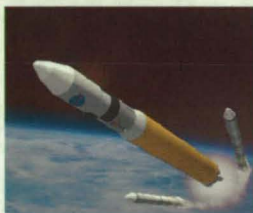




## Current Primary H<sub>2</sub> Focus



Assurance of liquid hydrogen as fuel for rocket engine tests and Space Shuttle launches.



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## LH<sub>2</sub> Storage



- LH<sub>2</sub> is transferred from tanker trucks to large spherical vessels for storage
- NASA is the largest customer in the US
- Most LH<sub>2</sub> is made commercially from natural gas



Did you know?

Immediately after hurricane Katrina in 2005, 700,000 gallons of LH<sub>2</sub> were transferred from KSC to industry to reduce the impact of the temporary reduction in hydrogen production.





## Long Term H<sub>2</sub> Goals



In support of human exploration of the Moon and Mars, several technologies are being developed that are based on hydrogen. Much of this effort leverages progress in the commercial sector for use in NASA unique environments and applications

- Hydrogen/oxygen propulsion systems for crew and cargo transportation vehicles
- PEM fuel cells with long life, high-capacity and high-density energy storage for spacecraft and planetary surface exploration
- Solid Oxide Fuel Cells for Aeronautics
- Cryogenic fuel storage
- Local resource extraction from Moon and Mars soil (hydrogen/oxygen for propellant, fuel cells & breathing)



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## Long Term H<sub>2</sub> Goals



### Space Exploration Resources

Confirming abundant water on the Moon would greatly simplify human life support and transportation by minimizing costly replenishment from Earth. In-situ processing (electrolysis or thermo-chemical) could convert water to hydrogen and oxygen for storage and use as rocket propellant, fuel cell reagents and breathing gas. Even without water, oxygen can be produced from lunar soil.

While lunar samples returned by the Apollo missions revealed that the Moon interior is devoid of water, subsequent robotic surveys (Clementine and Lunar Prospector) indicate the possibility of water ice in the cold dark areas of the lunar poles. If confirmed, the ice may be due to solar wind or past impacts with water rich comets. Estimates suggest there may be the equivalent a small lake (~ 1 billion cubic meters). If true, this much water would provide resources for many lunar and Mars exploration missions.



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## Alternatively Fueled Vehicles



Since 1999 Kennedy Space Center (KSC) has demonstrated hydrogen and fuel cell powered vehicles on the center and at the Visitor Complex. NASA plans to move from short-term demonstrations toward implementing hydrogen and fuel cell powered vehicles as a practical part of the vehicle fleet.



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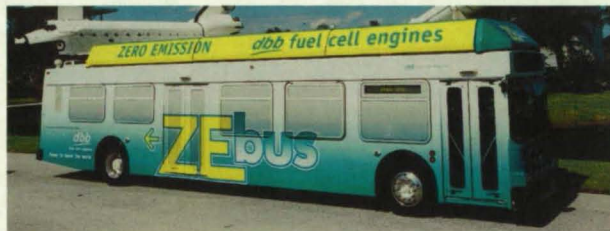
## H<sub>2</sub> For Ground Facilities



While NASA's resources are limited for institutional improvements, there is interest in outfitting various NASA field centers with hydrogen capabilities. Several centers have resident expertise in hydrogen systems and existing hydrogen infrastructure.

White Sands Test Facility (WSTF) plans a wind energy project for ground water remediation that could include fuel cell energy storage/conversion.

- Multiple centers have proposed the addition of hydrogen fueling stations for use with commercially provided demonstration vehicles.
- Other applications are possible (backup power supplies, utility carts, lawnmowers, etc)



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## Other H<sub>2</sub> Activities (Past and Current)

- Collaborations with Universities, Industry, and Government Agencies



- Safety

- Standards
- Training
- Testing
- Hazard Analysis



- Technology Development

- Fuel Cells (e.g. PEM, electrode catalysts, membrane electrolytes, solid oxide, methane, metal-air)
- Storage (e.g. metal hydrides, zero-boil off liquids, thermal simulation, carbon sorbents, insulations)
- Production (e.g. photo-chemical water splitting, ceramic membranes)
- Leak sensors (e.g. solid state electronics, paint pigments)



- Technology Transfer to Industry (e.g. private and public transport)

- Prize Competitions (e.g. orbital liquid fuel depot, lunar rover power)

- Outreach (e.g. vehicle demos, K-12 education)



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## KSC Alternatively Fueled Vehicle Demonstrations



Since 1999 Kennedy Space Center (KSC) has demonstrated hydrogen and fuel cell powered vehicles on the center and at the Visitor Complex.



Hydrogen has been described as the "ultimate alternative fuel," since it has zero carbon emissions and can be produced from many domestic sources. However, hydrogen technology must be embraced by consumers before its benefits can be realized.

Continuing the methods of partnering and cooperation that have proved successful with other alternative fuels, KSC has since 1999 demonstrated alternatively-fueled vehicles.







KSC has been an early adopter of alternatively fueled vehicles since 1994 when the natural gas fueling station was built, allowing NASA to:

- relate the use of hydrogen fuel as a ground transportation fuel to its experience in using hydrogen as an aerospace transportation fuel
- evaluate the use of hydrogen fueled vehicles in its fleet operations,
- comply with Alternative Fuel Vehicles (AFVs) mandates.

KSC, a high-visibility facility with many visitors, has the opportunity to demonstrate to the public at large that these new technologies exist, provide significant benefits, and can gradually gain acceptance for widespread use.



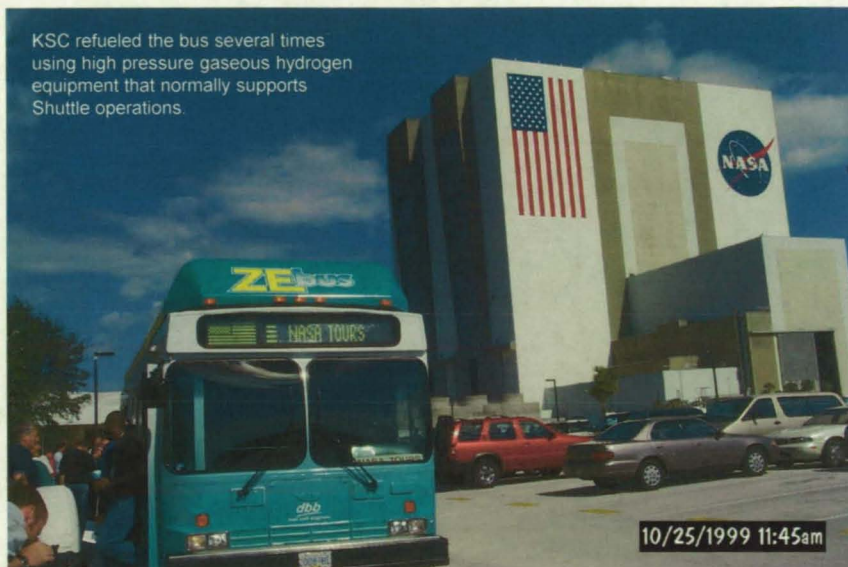
## Zero Emission fuel cell bus at KSC for 1 week in 1999







KSC refueled the bus several times using high pressure gaseous hydrogen equipment that normally supports Shuttle operations.



## Fuel cell powered vehicle at KSC for 1 week in 2004



In 2004, the fuel cell powered Ford Focus FCV was demonstrated and exhibited on the center and at the Visitor Complex.











Two fuel cell powered vehicles at KSC  
for 8 weeks in 2005



In 2005, two Honda FCXs powered by fuel cells were demonstrated at KSC.







## LH2 fueled vehicles at KSC for 6 weeks in 2007



In 2007, four hydrogen internal combustion engine (ICE) BMW Hydrogen 7's were demonstrated at KSC.





KSC's first  
LH2 fueling  
of a vehicle  
that's NOT a  
spacecraft!



These vehicles  
are fueled with  
liquid hydrogen  
(LH2). BMW  
brought their  
refueling  
dispenser/  
equipment and  
KSC supplied  
the LH2.

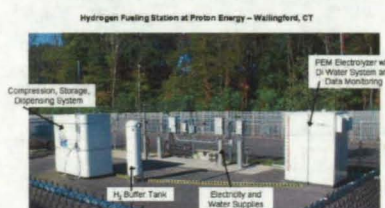






## Hydrogen refueling capability

- While NASA resources are limited for institutional improvements, there is interest in outfitting various NASA field centers with hydrogen capabilities.
- KSC now has 350bar (5,000psi) refueling capability and is working toward early adoption of hydrogen vehicles
- Stennis Space Center and Marshall Space Flight Center also use large quantities of hydrogen and are good candidates for early adoption of hydrogen vehicles
- Several centers have proposed adding hydrogen fueling stations for use with commercially provided demonstration vehicles. Other applications are possible (backup power supplies, utility carts, lawnmowers, etc).





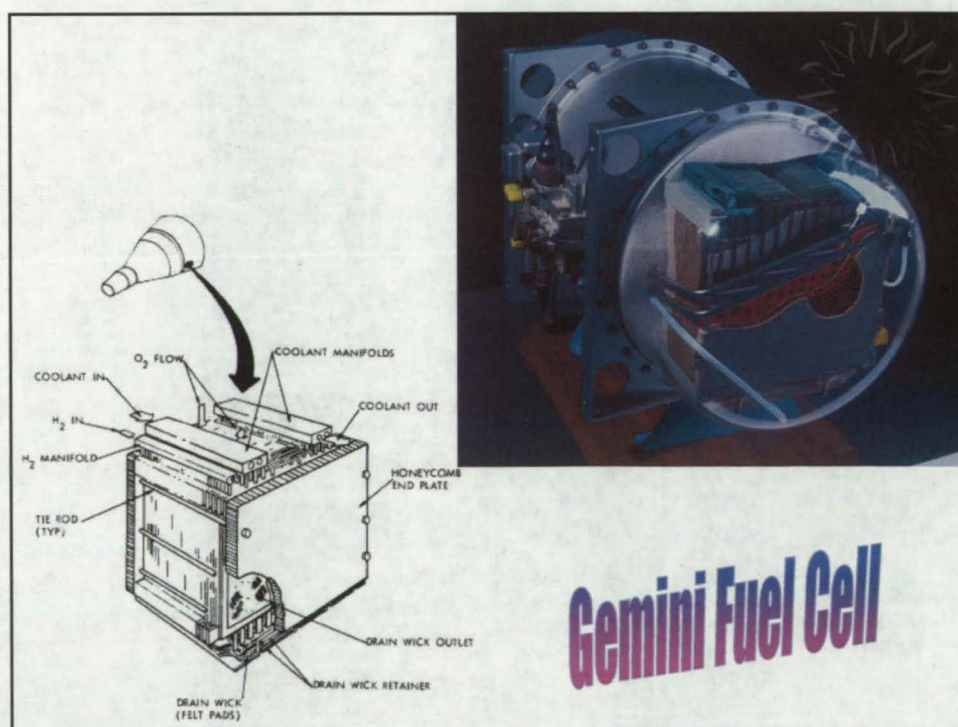
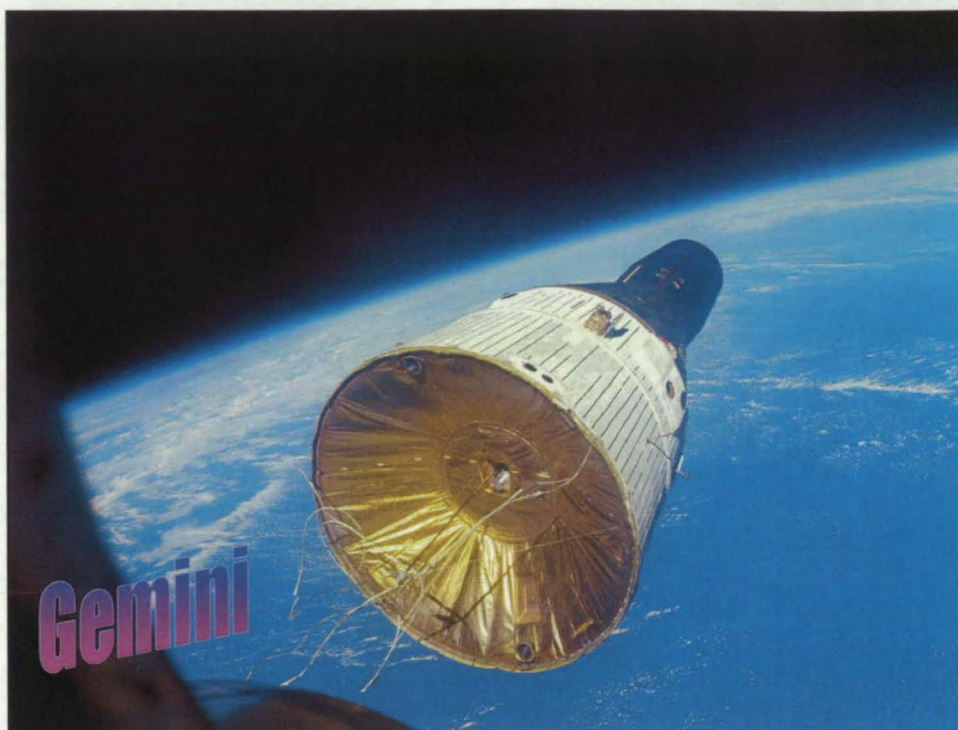
## A Pictorial History of Fuel Cells at NASA

The once obscure fuel cell was refined/developed by NASA to solve the dilemma of how to provide power for extended missions to space.

**Gemini**







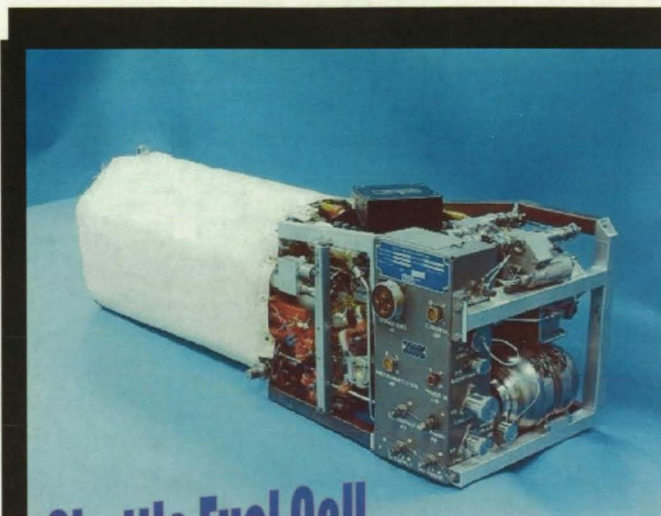








## Space Shuttle Fuel Cell



## Future Missions

- Altair lunar lander as currently planned will use a PEM fuel cell.

Artist's concept  
of a lunar lander  
on the moon's surface.



Since refinement/development by the space program, fuel cell technology has achieved widespread recognition by academia, industry, and government as a means for producing clean energy for the future. NASA is open to collaborations that benefit its goals and those of the nation.





## Acquisition and Distribution of Liquid Hydrogen



- NASA is the largest consumer of liquid hydrogen ( $LH_2$ ) in the US.
- NASA has purchased over 350 million pounds over 45 years, with millions of miles of safe delivery by truck, rail, and barge.
- KSC manages contracts, and monitors markets and technologies for availability, costs, detection, production, safety, storage, and transport.



Tanker being filled before delivery. Tanker trucks are so well insulated that they can haul  $LH_2$  for hundreds of miles without losses to boil-off.





## Liquid Hydrogen Delivery



LH2 is transported from commercial vendors to NASA Centers on the public roads via cryogenic (having very low temperatures) tanker trucks.

Approximately 50 tanker trucks are driven in for each shuttle launch to provide the necessary LH2.

Shuttle main engines burn about 500,000 gallons (295,000 lbs) of LH2. Another 239,000 lbs are lost due to boil off and transferral. The fuel is stored at minus 423°F. The engine exhaust is primarily water vapor.



LH2 tankers at destination prepare to fill 850,000 gallon storage tank.





## On-site Distribution



Stennis Space Center uses barges for on-site distribution.



All other sites use tankers and fixed storage.



## Storage tank at KSC





## White Sands Testing Facility and Hydrogen



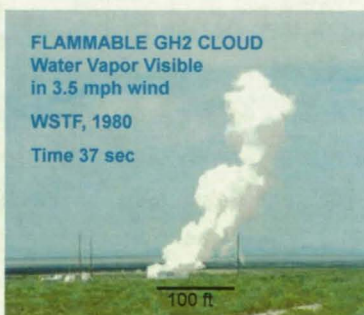
### Testing

White Sands Test Facility (WSTF) has a wide variety of resources to draw upon in assessing the fire, explosion, compatibility, and safety hazards of hydrogen and other propellants.



2000 lb LH2-Lox Launch Accident  
Simulation

FLAMMABLE GH<sub>2</sub> CLOUD  
Water Vapor Visible  
in 3.5 mph wind  
WSTF, 1980  
Time 37 sec





## Safety Standards

The White Sands Test Facility collaborates with a variety of organizations to ensure up-to-date safety information and standards for Agency use and share NASA hydrogen expertise in the development of national and international standards:

- WSTF Personnel hold Chairman and Secretary duties for AIAA's Hydrogen Committee on Standards: "Guide to Safety of Hydrogen and Hydrogen Systems, (ANSI/AIAA G-095-2004)"
- Share hazards research and best practice experience: DOE, Sandia National Laboratories, and Pacific Northwest National Labs
- ISO Technical Committee 197 Hydrogen Technologies: "Basic considerations for the safety of hydrogen systems, (ISO/PDTR 15916)"
- American Society for Testing and Materials
- National Fire Protection Association: Hydrogen Technologies (NFPA 2) standard in development



## Training

WSTF has provided safety training courses in specialized areas since 1987

- Taught at NASA centers, government and industry locations
- Customized content can be arranged
- Hydrogen courses currently offered through the NASA Safety Training Center (NSTC) or by special arrangement:
  - Hydrogen Safety [2-day seminar (037 - NSTC)]
  - Safety in Hydrogen Systems Operations [4-hour instruction (054 - NSTC)]
- Other courses offered include: Oxygen Safety, Hypergol Safety, and COPV Inspection





# Hazard Assessment

Experience in performing hydrogen hazard assessment on components, systems, and facilities using specially developed protocols:

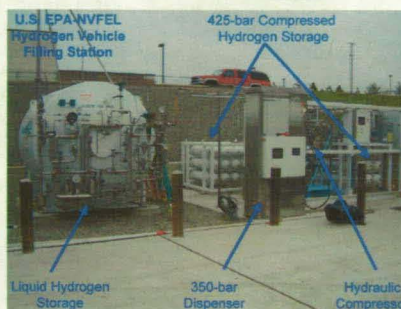
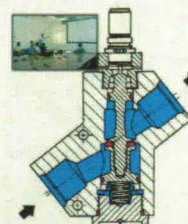
[Hydrogen Hazards Assessment Protocol for Components and Systems (WSTF-IR-1117-001-08)]

Analysis considers:

- Environment and Operating conditions
- Material compatibility
- System design and best practice
- Flammability, Ignition, & explosion
- Exposures to personnel and equipment
- Consequences (before and after mitigations)

Provides logical methodology, documentation of findings, mitigations and recommendations

Component Analysis



Facility Siting Assessment, Ann Arbor, Michigan